Beryllium Beyond the Neutron Drip-Line: ^{13}Be

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New (p,2p)-data studying resonances in the unbound ^{13}Be-system is being analysed within the R3B collaboration. The reaction and the experimental setup used in order to obtain these data are briefly explained and followed by a summary of the analysis method and the current status of the analysis.

KEYWORDS: unbound nuclei, (p,2p) reaction, ^{13}Be,

1. Introduction & Motivation

In the framework of the R3B Collaboration (Reactions with Relativistic Radioactive Beams) the s393 experiment was performed at GSI (Darmstadt, Germany) in the late summer of 2010. The goals of the experiment were manyfold containing studies of the r-process as well as nuclear structure studies using quasi-free scattering reactions. The experiment was utilising kinematically complete measurements at relativistic energies. This article is focused on the study of the beryllium isotope ^{13}Be using (p,2p)-reaction starting from a beam of ^{14}B. The unbound ^{13}Be system provides information on the nuclei formation and shell structure close and beyond the neutron drip-line.

This nucleus has been studied before by break-up reactions starting from the two-neutron halo nucleus ^{14}Be at GSI [1] as well as at RIKEN [2]. Aksyutina et. al. [3] recently published new data from GSI and discussed all the available information, including also results from GANIL [4] this latter experiment had used ^{14}B as incoming beam. The system ^{13}Be is interesting for understanding the break-up and formation of extreme nuclear systems. In the present study, we are approaching ^{13}Be from ^{14}B with the added value of gamma-ray detection.

2. How-To: Knock-out reaction

The exotic nuclei ^{13}Be was produced in a (p,2p)-reaction using inverse kinematics; a primary beam of ^{40}Ar was accelerated by the linear accelerator (UNILAC) followed by the synchrotron (SIS) to an energy of 490 MeV/u and let to impinge on a Beryllium target, the so produced secondary beam was separated by the Fragment Separator (FRS). The selected isotope ^{14}B was let to interact in a CH_2 target producing ^{13}Be via (p,2p) knockout-reaction. The neutron-unbound ^{13}Be rapidly separates into ^{12}Be + n with a lifetime in the order of 10^{-21}s.

The interaction is very rapid, taking place directly between one beam and one target -nucleon [5]. At this high energies one can regard the target-nucleon to be at rest and thus the binding energy can be neglected, this is called quasi-free scattering. In our case and in the inverse kinematic picture, the incoming boron nuclei lose one proton while kicking out one from the target.

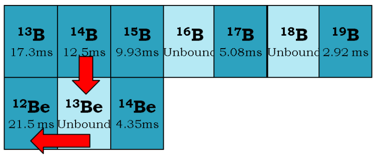

Fig. 1. The decay path along the nuclei chart. Via the (p,2p) reaction, the ^{14}B goes to ^{13}Be, which breaks up and ending in ^{12}Be.

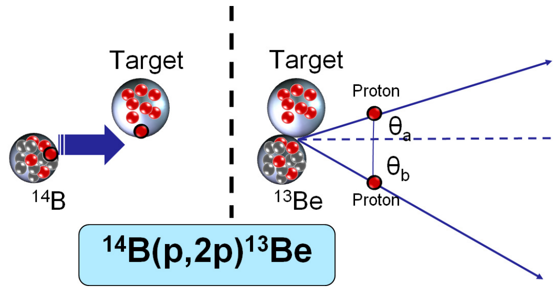

Fig. 2. The ^{14}B incoming beam interact with the CH_2 target, in the (p,2p)-reaction the two protons are emitted with an outgoing angle of 90° in the laboratory system.

3. Setup

The R3B setup used in the s393 experiment (and with small changes in many experiments before) is located in Cave C at GSI. It is divided in four main sections; monitoring detectors of the incoming beam, detectors surrounding the target, the dipole magnet, out-going beam detectors. The out-going beam is detected in three branches: neutron, proton and heavy fragments due to the kinematics of each species. A sketch of the setup is displayed in the figure 3.

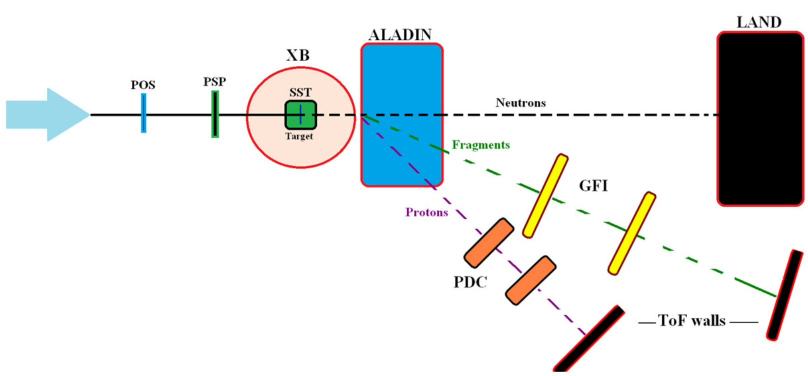

Fig. 3. A sketch of the R3B Set-up in Cave C at GSI. The three branches following the target are displayed and the name of the different detectors are indicated. The incoming beam of the FRS is shown by the blue arrow.

The incoming beam is analysed by Time of Flight measurement using the two scintillators, the S8 positioned close to the FRS and the POS positioned inside Cave C. There is also a Position Sensitive silicon Pin diode (PSP) for charge selection.

Surrounding the target was placed the Crystal Ball(XB), composed of 162 NaI scintillators for detection of both the gamma-rays as well as the (p,2p)-protons emitted in the reaction. Two separate amplification chains for the PMT-readout were thus used in order to make possible the simultaneous detection of high-energy protons in parallel with low-energy gamma rays. Further, the position and energy loss of the out-going reaction-fragments were detected in a box (SST), composed of 8 double-sided silicon micro-strip detectors surrounding the target . Three different targets, CH_2, lead & carbon were mounted on a target-wheel that was remote-controlled. The outgoing beam is analysed by the large dipole magnet ALADIN, which bend the forward going protons and fragments in the direction of respectively detection system and out of the way of the the Large Area Neutron Detector(LAND) placed 12m downstream the target. LAND, composed from 10 planes of sandwiched sheets of iron and plastic scintillators, detects position and time-of-flight and thus gives the emission angle and the energy of the emitted neutrons.

The fragment branch is composed by a pair of fibre detectors (GFI) for position separation, and a ToF-Wall, with 8x8 plastic scintillators for energy loss and time-of-flight measurement. The setup also includes a proton branch with a drift chamber and a time of flight wall, however, this was not used for this reaction channel, as the (p,2p) proton-pair are emitted outside the angular acceptance of the ALADIN magnet.

4. Analysis

4.1 Reaction-channel identification

The ^{13}Be is an unbound nuclei with extremely short lifetime, the nuclei will thus break up into ^{12}Be+n system. As previously explained, the beam leaving the FRS contains a cocktail of different species. In order to select the channel of interest, the incoming Z and A/Z is calculated from the Time-of-Flight between POS and PSP and the energy-loss in PSP. The species involved in the ^{14}B(p,2p)^{13}Be reaction are identified as follows; first in the SST surrounding the target we select the beryllium-isotopes (Z=4), secondly after having chosen the right outgoing charge, the mass channel (A=12) is tracked using the Time-of-Flight and the position in the fragment branch. The last step in order to identify the channel is to ensure that one neutron is detected in the LAND detector.

4.2 Results

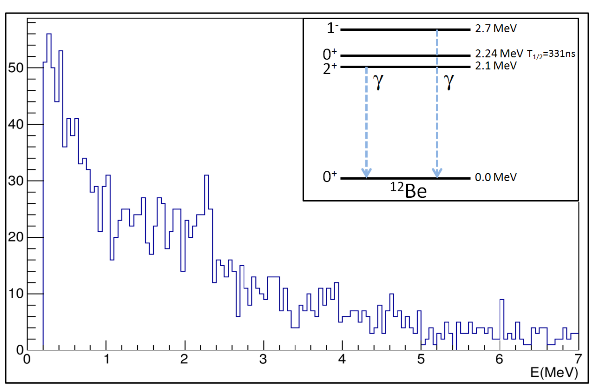

Fig. 4. The γ-spectrum obtained from ^{13}Be. The inset display the low energy γ-decay scheme in ^{12}Be

To be able to distinguish between the different states populated in the reaction, it should be possible to gate on specific γ-lines (2.1 and 2.7 MeV) from known excited states in ^{12}Be, see the inset of figure 4. However, the gamma spectrum obtained in our experiment has only one prominent peak, which does not fit very well to any of the predicted values. By placing gates around the peak (on-peak and off-peak) in the obtained γ-spectrum and projecting the relative energy spectrum of (^{12}Be+n) we cannot detect any feature-difference but statistical fluctuations. The conclusion that can be drawn is that no γ-decaying excited state in ^{12}Be has been populated and therefore only 0^+ states have been fed.

In order to extract further information about the ^{13}Be structure, we calculate the relative energy from the outgoing fragment and the neutron, using the following equation:

$$E_{rel} = \sqrt{M^2_{^{12}Be} + m_n^2 + 2 \cdot m_n M_{^{12}Be} \gamma_n \gamma_{^{12}Be} [1 - \beta_n \beta_{^{12}Be} \cdot Cos(\theta_{^{12}Be-n})]} - M_{^{12}Be} - m_n \qquad (1)$$

This expression have two main parameters:

- The angle between the neutron & the fragment.
- The velocity from both which is applied by the β and the γ.

The analysis of these data are currently ongoing, the combination of the energy information coming from the equation 1 and further analysis of the gamma spectrum from the figure 4 should shed light on the resonance structure of the ^{13}Be fed from ^{14}B.

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References

[1] H. Simon et al: Nucl. Phys. A **791** (2007) 267
[2] Y. Kondo et al: Phys. Lett. B **690** (2010) 245
[3] Y. Aksyutina et al: Phys. Rev. C **87** (2013) 064316
[4] G. Randisi et al: Phys. Rev. C **89** (2014) 034320
[5] T. Aumann et al: Phys. Rev. C **88** (2013) 064610